Passive means to detect hot trolley insulators

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Abstract

Faulty insulators on mine trolley/track haulageways may allow leakage of currents into the mine roof, which may ultimately result in the combustion of the roof material. The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL), devised a passive means to detect overheating insulators on direct current systems. The detector consists of a spring- loaded cartridge that ejects a reflective streamer of white Teflon tape when subjected to elevated temperatures. The cartridge assembly can easily be installed over the outer metallic shell of an existing trolley line insulator. If an insulator overheats due to ground leakage currents, the visible streamer alerts mine personnel traveling on the haulageway.

Introduction

Electrical trolley systems are used for mineral haulage and for the movement of personnel and supplies in nearly 50 mines in the United States. These mines are located mostly in southwestern Pennsylvania and West Virginia. These systems use a trolley wire energized with 300- or 600-V direct current. The current powers vehicles running on a network of permanently installed steel tracks. The bare copper trolley wire and a feeder wire are suspended approximately every 6 m (20 ft) from insulators that are anchored into the roof by bolts. The purpose of the insulators is to prevent current from flowing to the grounded return track via the overlying strata

Trolley insulators are expected to maintain dielectric strength in dusty and wet environments. Coal and rock dust accumulations, as well as acidic drainage and condensation, may jeopardize the insulator's integrity. Leakage currents from the trolley wire into the roof strata can heat the insulator as well as the immediate area in which the suspended bolt is anchored. If not detected and corrected, this may result in the ignition of roof coal, which could lead to a catastrophic mine fire. The likelihood of such fires on dc trolley systems can be minimized if deteriorating insulators can be promptly detected and replaced.

An insulator and the surrounding strata subject to leakage currents may be discolored or may have an odor. However, they also may exhibit no physical evidence of deterioration. Leakage can be confirmed through voltage measurements across the insulator. But this can be a time-consuming, tedious task considering that there are thousands of insulators distributed over miles of haulageway. From a slow-moving vehicle, a portable infrared detector can be used to scan for heat on the insulators and in the roof. This can be effective when done regularly, but it cannot detect impending failures between examinations. An insulator integrally designed to give some indication of the presence of leakage currents could be detected and replaced promptly. Such a device, using either audio or visual techniques, was conceptualized in prior research (Gillenwater and McCoy, 1981). However, the design effort never proceeded to the prototype stage due to product cost concerns.

This report documents the accomplishments of a research project in support of the Pittsburgh Research Laboratory's (PRL) goal of enhancing safety for underground miners. The specific objective of this project was to devise a passive means to detect overheating insulators on mine trolley/track haulageways. The results of this work have the potential to minimize the incidence of overheating insulators and related fires on mine dc trolley systems.

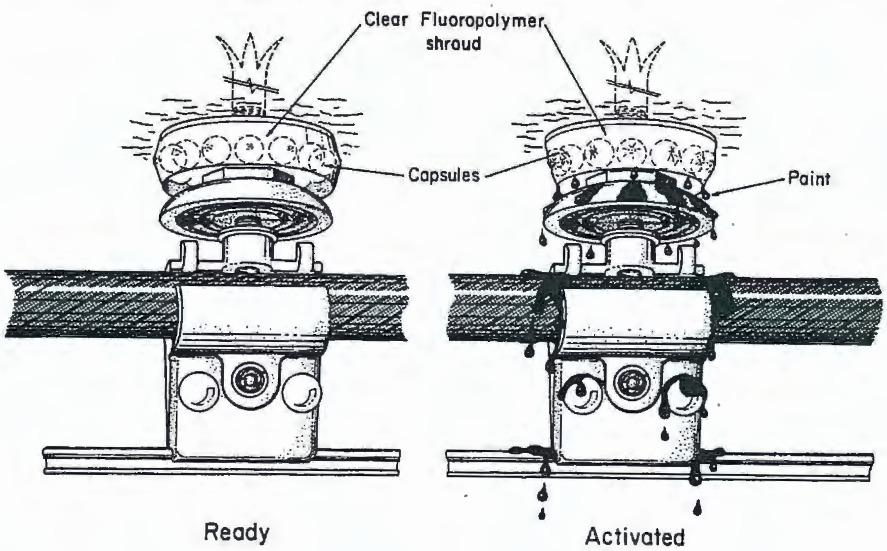
General design criteria

The number of trolley systems used for haulage in underground coal mines is diminishing as new mines opt for belt haulage and diesel power. Consequently, those mines still employing trolley and track for haulage tend to be older and have a limited operational life; they also tend to be small-capacity operations (Sanda, 1991). The haulageways in these mines must still be maintained, but there may be little incentive for costly improvements. Wholesale replacement of system components such as insulators is simply not justified economically. Accordingly, any thermal-indicating means for trolley insulators must be easily retrofitted on existing insulators. Also, it must be inexpensive compared to the cost of a new insulator.

To be effective in preventing fires, a thermal indicator must activate in the presence of leakage currents at the lowest practical temperatures. However, it must not react to other sources of heat, such as idling mine locomotives. Reliability dictates that it be simple in both design and function. Ideally, it should be a passive device that requires no external power to operate. The same environmental contaminants that

FIGURE 1

Thermal detection using point-filled capsules.



contribute to leakage currents must not interfere with indicator function. Finally, installation of the indicator on the insulator must not introduce new hazards.

Approaches

A number of thermal-indicating concepts were considered at the outset. These included paint-filled capsules, an encapsulated liquid, a deflective polymer, a bimetallic strip and a spring-loaded cartridge held in place with wax. Each concept was evaluated and critiqued prior to the construction of a prototype.

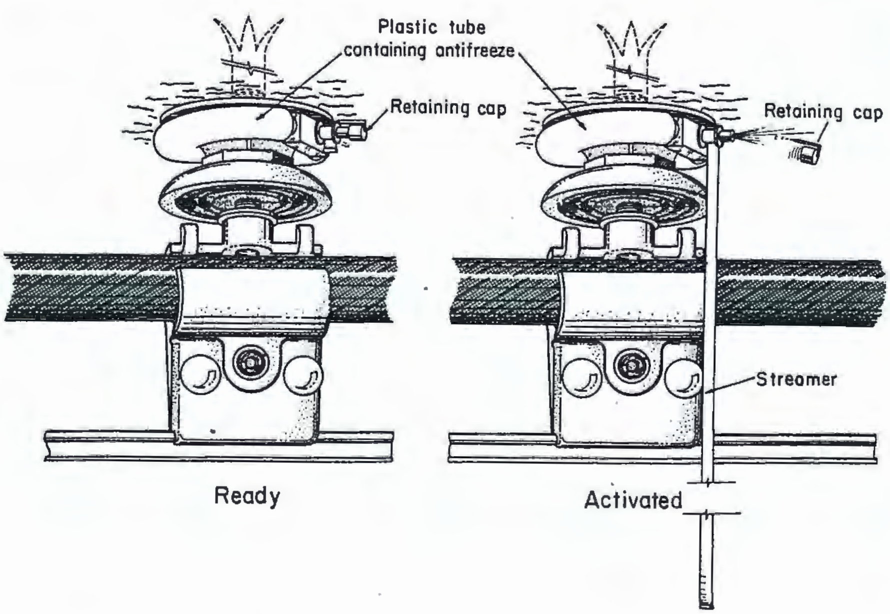
A preliminary idea involved mounting a clear fluoropolymer shroud around the insulator body (Fig. 1). Paint-filled capsules would be contained within the shroud adjacent to the insulator housing. An overheating insulator would cause the shroud to shrink around the capsules. The capsules would be pierced by adjacent sharp protrusions, releasing paint over the exterior of the insulator. This passive technique had several advantages. It required no external power to activate, and the shroud material was flame retardant. However, the capsule and shroud assembly would be difficult to install without removing the insulator from service. In addition, the paint might be difficult to detect once the shroud was covered with dust.

Another concept involved placing antifreeze inside a plastic tube that would be wrapped around the insulator body (Fig. 2). Insulator leakage current would heat the antifreeze inside the tube. With sufficient internal pressure, a retaining cap would be ejected, and a spool of Teflon tape would unroll. The weighted tape would unwind by gravity. This white reflective streamer flapping in the ventilating air would be easily visible to personnel traveling in vehicles. In addition, the antifreeze would remain liquid in areas of the haulage near the portal where temperatures may drop below freezing. But, no easy way could be found to retrofit the tubing on an insulator without losing fluid.

A third possible method featured a polymer disk that would be installed over the top of the insulator (Fig. 3). A cartridge containing a Teflon streamer would be mounted on top of the disk. When heated, this disk would deform and a wax seal inside the cartridge would melt. The seal is intended to keep dirt from fouling the streamer. The streamer would unroll by gravity. This simple concept required no external power. However, after careful consideration, it was felt that the wax would not reliably melt, as the polymer disk was a poor heat conductor.

FIGURE 2

Thermal detection using pressurized liquid.



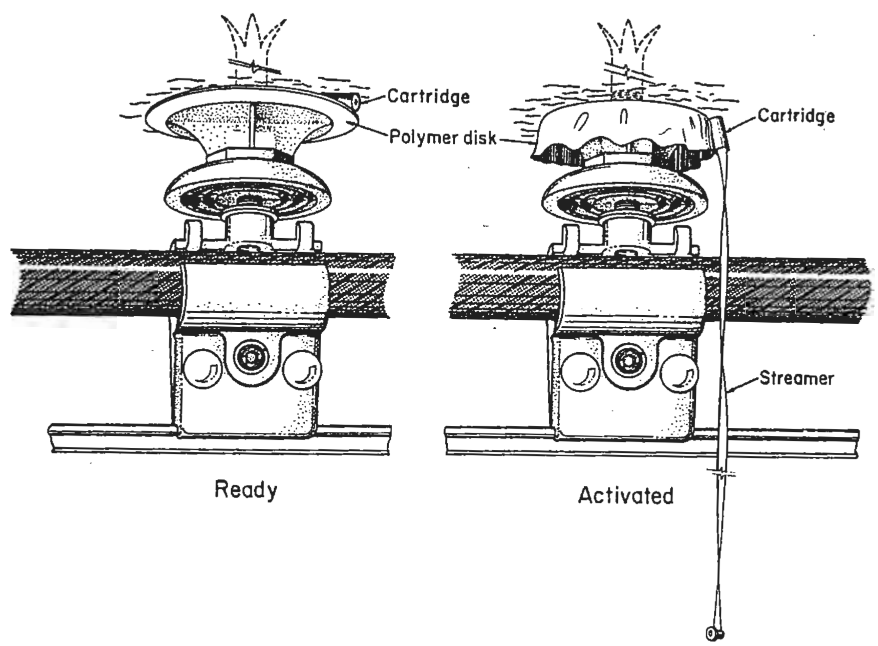
A fourth mechanism relied upon the movement of a bimetallic strip and gravity to activate a streamer. For maximum deflection, a spirally wound strip was needed. An engineering analysis of this design showed that to produce an angular deflection in excess of 90° required a strip so large as to be impractical when mounted on an existing insulator (Crest Manufacturing Applications Manual, 1995).

The final concept that was envisioned used a cartridge containing a spring-loaded streamer that was brazed to an adjustable hose clamp (Fig. 4). The clamp would be installed around the insulator housing. When leakage currents caused the insulator to become elevated in temperature, heat would be transferred via the clamp to the cartridge.

Temperature-sensitive wax seals would hold the spooled streamer in place. At the melt temperature specified for the wax, the spring would eject the spooled streamer out of the cartridge. Gravity would then pull the nonconductive streamer downward where air currents along the haulageway would cause it to flutter noticeably. This design was simple and was easy to install on the insulators in service. It had the potential to be inexpensive, while providing a recognizable warning signal to vehicles traveling through the haulageway. Consequently, the design was selected, and its reliability would subsequently be evaluated through prototype tests.

FIGURE 3

Thermal detection using deflective polymer disk.



Prototype construction

To facilitate a better understanding of the concept, a prototype was assembled as follows: A hose clamp with a suitable adjustment range was selected for the design. Made of stainless steel to prevent corrosion, this clamp would easily fit around commonly used insulators. For economy, a 44-magnum brass cartridge was chosen to house the spring-loaded streamer. This cartridge was modified by enlarging the primer opening. Taking care not to deform its circumference, the brass cartridge was brazed to the clamp. A brass rod was then machined as a spool to fit within the cartridge. Teflon tape was carefully wound around the spool. This assembly was inserted into the cartridge along with a compressed stainless-steel spring. A stainless-steel machine screw and nut temporarily secured the spool and spring within the cartridge. A heat gun was used to affix wax in two locations. On the inside of the cartridge, a temperature-sensitive wax pellet was used as the trigger mechanism for the spring to eject the spool wound with the Teflon streamer. An exterior wax seal prevented dirt from getting inside the cartridge. The design is fully documented in a patent application (Hudson, 1996).

Laboratory tests

The thermal indicator must react before heat generated by leakage currents through resistive paths can ignite nearby combustibles. These paths may be present on the surface of the insulator in the form of moisture and dirt. In the case of a cracked insulator, the resistive path for leakage current may be internal. In addition, heat may be generated in the roof as the current seeks to return to the grounded rail. To preclude the ignition of coal dust accumulations on the external surfaces of the mechanical or electrical components, Title 30 of the Code of Federal Regulations imposes a 150° C (302° F) limitation (US Code of Federal Regulations, 1993). In addition, some direct current trolley insulator manufacturers specify a maximum operating temperature of 121° C (250° F) (Dubina, 1981). Due to thermal resistance, an indicator brazed to a clamp wrapped around the insulator housing will lag in temperature rise. Consequently, the temperature at which the device activates must be less than the limitations imposed on the insulator housing. Laboratory tests were planned to quantify this temperature gradient and facilitate selection of the temperature rating for device activation. These tests would also demonstrate whether the thermal indicator was able to sense heat from below as well as from above where it is mounted on the insulator.

A thermal indicator was installed on an insulator suspended on a test stand. A 2-ohm, 250-W wire-wound resistor was placed above the insulator to serve as a heat source. Type T, #24 AWG thermocouples were fixed at key locations on the insulator and detector. The thermocouples were connected to a 32-channel data logger that was programmed to read and transmit temperature data to a personal computer. Commercial data- acquisition software was used to collect the data, display them in real time and store them on a disk. With 30 V applied to the resistor, heat was generated above the insulator and, through conduction via the mounting bolt, was gradually transferred to the insulator and detector. Plots of temperature and time are shown in Fig. 5. It can be seen that, with a heat source from above, the difference in temperature between the insulator housing under the clamp and the cartridge was approximately 35° C (95° F). Similar results were obtained with the resistive heat source below the insulator. For maximum sensitivity, the temperature rating selected for the wax pellet was 50° C (122° F). Thus, the streamer should activate before maximum rated insulator temperatures are reached, regardless of the location of the heat source.

Additional tests were planned to gauge the reliability of the design. One hundred wax-sealed cartridges were constructed and mounted on a 1- by 1.5-m (3- by 5-ft) aluminum panel (Fig. 6). This panel was inserted into a 2.7-m^3 (95-cu ft) air oven, and the temperature in the oven was gradually increased from ambient at the rate of

FIGURE 4

Hot insulator detector prototype.

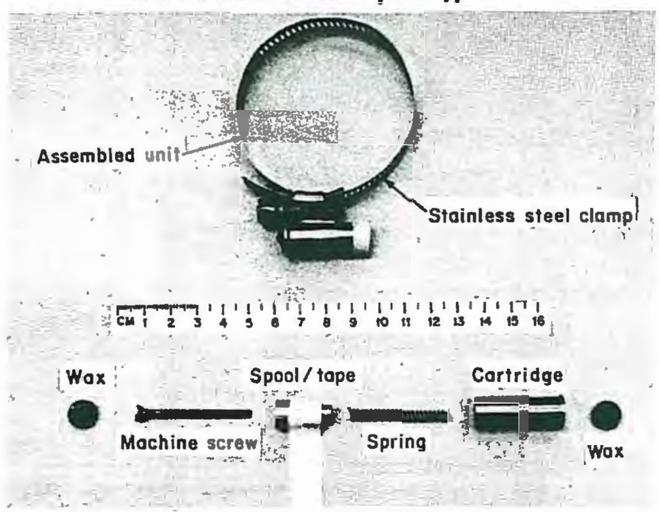
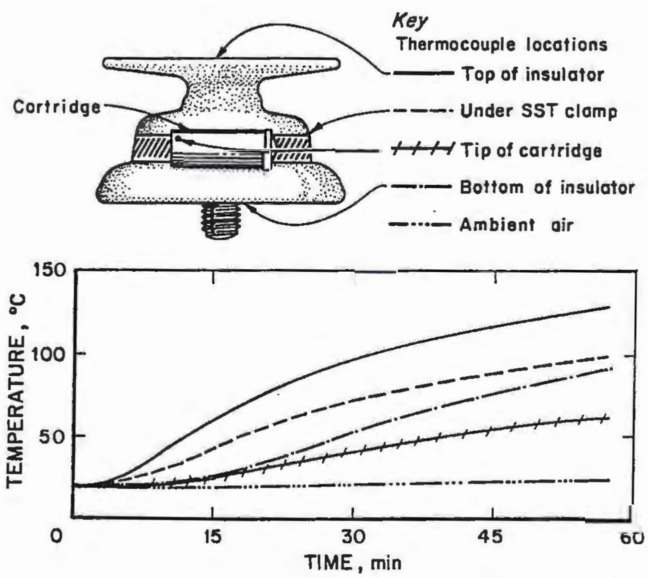


FIGURE 5

Temperature gradients with heat source above insulator.



25° C (77° F) per hour. Ninety-seven of the cartridges successfully ejected the Teflon streamer within ±5° C (±9° F) of the target temperature of the wax. An examination of the three that failed to activate revealed deformities in the brass cartridges that hindered spool ejection. Careful packaging and handling of the device should preclude this damage in storage and transit. However, an installed device would be vulnerable to damage from impacts by a trolley pole.

Condensation may form on underground surfaces during the summer months when warm, humid air is drawn into the mine. This moisture may cause sudden arcing across trolley insulators, especially on 600-V systems. Laboratory tests were conducted to determine if the thermal indicator would activate in the presence of an electrical arc and if the indicator would be damaged by the arc. A 600-V direct current supply in PRL's Mine Electrical Laboratory was placed in series with 150 mH of inductance. Consisting of large air-core windings, this inductance simulated the electrical characteristics of a mine trolley/track haulageway. Its presence facilitates electrical arcs on these systems. In the laboratory, the arc was initiated by placing a #18 AWG fuse wire between the insulator outer housing and center threaded stud. Upon energization, the fuse wire quickly melted leaving an ionized path for the electrical arc. This arc was maintained for 4 to 5 sec. During this time, there was significant erosion of the insulator stud and housing. The rapidly escalating heat activated the insulator detector nearly instantaneously. In some cases, the Teflon streamer remained intact after arc interruption. However, most of the time, the arc energy severed the streamer and it fell to the ground. Consequently, the insulator detector cannot be effective in the case of an arcing trolley insulator.

Additional test recommendations

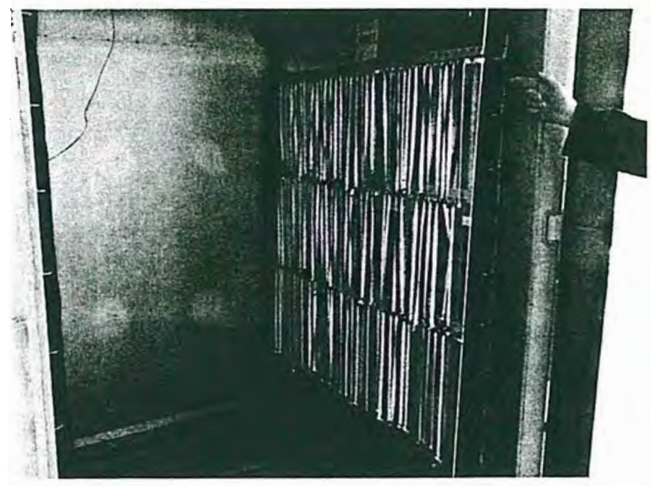
It is recommended that the prototype clamp and cartridge assembly undergo additional tests (Trelewicz, 1981) to determine appropriateness for mine duty. These tests, in accordance with MIL Std 810C (Military Standard 810C, 1984), should include high and low temperatures that approximate the cyclic temperature extremes, i.e., -29° to 38° C (-20° to 100° F), that may be experienced during storage and operation. In addition, a thermal-shock test should be conducted to determine the effect of sudden changes in these temperature extremes. To measure the effect of warm, humid air, the indicator should be subjected to 38° C (100° F) at 95% humidity. A mechanical shock test would gauge the ability of the device to withstand drops of up to 915 mm (36-in.) that may occur during shipment. A vibration test of 1.5 *G* up to 200 Hz would simulate the motion of common carrier shipping. The device should be exposed to dust concentrations of 10 mg/m^3 at both 91.4 and 533.4 m/min (300 and 1,750 fpm), and their effects on the operation should be noted. A corrosion test, performed in accordance with ASTM Standard B117 (American Society for Testing and Materials, 1997), with an acidified spray would complete the evaluation of the assembly. Following exposure, the assembly operation should be tested through exposure to heat. Once installed on an insulator, a dielectric strength test (American National Standards Institute (ANSI) C59.48, 1994; Institute of Electrical and Electronic Engineers (IEEE), Standard No. 4, 1995) should be conducted to determine if the addition of the metallic clamp and assembly affects the original insulation qualities of the insulator.

Summary and conclusions

NIOSH's PRL has devised a passive means to detect overheating insulators on mine trolley/track haulageways. The detector consists of a spring-loaded cartridge that ejects a reflective streamer of white Teflon tape when subjected to elevated temperatures. The adjustable activation temperature of the cartridge is determined by the melting of a wax seal. The cartridge assembly is attached to a stainless steel clamp that can easily be installed over the outer metallic shell of an existing trolley insulator. When an insulator overheats due to ground leakage currents, the visible streamer alerts mine personnel traveling through the haulageway. Laboratory tests showed that, when installed on an insulator, the device could effectively warn of the presence of heat from both above and below. Air-oven tests established that the reliability of a 100-sample lot of the spring-loaded cartridges was approximately 97%. However, the Teflon streamer may not remain intact should the insulator be subject to arcing. Such faults on mine trolley systems are better detected by a neural network-based algorithm recently devised at PRL (Peterson and Cole, 1997). Nevertheless, implementation of the research documented in this report has the potential of minimizing the incidences of overheating insulators and related fires on mine dc trolley systems. ■

FIGURE 6

Fired cartridges following test in air oven.



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